Final Report to the

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for International Ultraviolet Explorer Observing Time and Support

for

SPECTROPHOTOMETRY OF EMISSION-LINE STARS IN THE MAGELLANIC CLOUDS

Contract Number NAG 5-833

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The strong emission lines in the most luminous stars in the Magellanic Clouds indicate that these stars have such strong stellar winds that their photospheres are so masked that optical absorption lines do not provide an accurate measure of photospheric conditions. In the research funded by this grant, temperatures and gravities of emission-line stars both in the Large (LMC) and Small Magellanic Clouds (SMC) have been measured by fitting of continuum ultraviolet-optical fluxes observed with IUE with theoretical model atmospheres. Preliminary results from this work formed a major part of an invited review "The Distribution of Types of Luminous Blue Variables" (B. Bohannan 1989, in *IAU Colloquium 113, The Physics of Luminous Blue Variables*, ed. K. Davidson, A.F.J. Moffat, H.J.G.L.M. Lamers (Dordrecht: Kluwer), pp. 35-44). Interpretation of the IUE observations obtained in this grant and archive data were also included in a talk at the First Boulder–Munich Hot Stars Workshop ("Of/WN Stars: More than a morphological distinction?", B. Bohannan, in *Properties of Hot Luminous Stars*, Astron. Soc. of the Pacific Conference Series, Volume 7, ed. C. D. Garmany, pp. 39-43). Final results of these studies are now being completed for publication in refereed journals.

Two diagnostics have been considered here to probe the photospheric conditions of hot, luminous stars. One involves a comparison of observed uv continua with calculations from theoretical atmospheres (most commonly those of Kurucz 1979, *Ap. J. Suppl.* **40**, 1), the other is the calibration of ultraviolet line strengths with spectral type by Shore and Sanduleak (1984 *Ap. J. Suppl.* **55**, 1). We had used the first diagnostic with success for LMC emission-line stars like S Doradus that have Fe II and [Fe II] in emission (Bohannan and Doggett, 1987, *B.A.A.S.* **19**, 706), where we found that these stars apparently span a wide range of effective temperatures and luminosities, not just those near the Humphreys-Davidson limit. The temperatures we measured tend to be hotter than previous studies because of use of calculated Kurucz atmospheres rather than just using his published grid. This work is in pre-print stage and will be submitted for publication in the coming months. The second technique cannot be used for strongest emission-line stars such as many these stars because there are really no true photospheric

absorption lines. For stars with less extreme emission, we find that the two diagnostics do not produce a consistent result as there is a range of temperatures for a given spectral type depending on the ion. While the lower metal abundance in the LMC compared with the Galaxy may be contributing to this inconsistency, the likely origin lies in the nature of the winds flowing out from the LMC emission-line stars for the largest inconsistencies occur in stars with dense, slow flowing winds (e.g. the stars with Fe II and [Fe II] in emission like S Doradus). An additional source for the inconsistency may be in the nature of the calibration stars. This is a line of investigation for future work as better spectral type calibrations come available in the LMC through the work by Dr. E. L. Fitzpatrick and as more physically realistic model atmospheres are calculated with mass loss and spherical geometry.

The IUE observations obtained in this series of grants are also contributing significantly to understanding of what are called slash stars, a designation used to indicate an ambiguity in defining a spectral type. The stars of interest here have the spectral character of both Of and WN types. The prototypes of this class are in the Large Magellanic Cloud (Bohannan and N. R. Walborn, P.A.S.P. 101, 520-527, 1989) and have been observed as part of this project. One of these stars HD 269858 (R127) has recently undergone an outburst and is now designated a Luminous Blue Variable (LBV). A set of candidate Of/WN stars have been identified in the Galaxy (P. S. Conti and B. Bohannan 1989, in *IAU Colloquium 113, The Physics of Luminous Blue Variables,* ed. K. Davidson, A.F.J. Moffat, H.J.G.L.M. Lamers (Dordrecht: Kluwer), pp. 297-298.).

We have extracted IUE spectra from the archives of the candidate slash stars for comparison with the LMC Of/WN stars. At first, from looking at only one example, HD 152408, one explanation for the strong emission lines is that the winds are slower and denser. After consideration of the entire set, we now conclude that the situation is not so simple and that more detailed analysis must be undertaken with an appropriate model atmosphere code. An atmospheric and spectroscopic analysis has been completed by Dr. Werner Schmutz and myself for HD 152408 using IUE and ground-based spectroscopy which indicates that this star has a surface helium abundance of N[He] = 0.4, an abundance which indicates that nuclear processed material is now on the surface of this star. This very remarkable result, now being written up for publication, provides very significant clues to the evolution of massive stars. In other work with my colleagues in Boulder, we have found that most, if not all supergiant O and Of stars have enhanced helium (B. Bohannan, S. A. Voels, D.G. Hummer, and D. C. Abbott 1990, *Astrophysical Journal,* 20 December; and earlier papers in the series). It appears then that the Of/WN slash stars represent a later phase in the evolution of massive stars from spectral type O to the Wolf-Rayet phase.

Progress on this grant has been slowed by lack of personnel. It was originally intended that the bulk of the day-to-day work would be carried out by a graduate student Research Assistant. However, the funds allocated by IUE were insufficient to employ an RA full-time (*i.e.* 50% during the academic year and 100% over the summer). Because only part-time support is available (usually supplemented with a teaching assistantship to

provide the equivalent of full-time), the two graduate students I have employed have stuck with the project for only a semester before finding full-time support with another research program. This has substantially limited progress for they just get up on the learning curve and then leave for greener pastures. For the principal investigator, research is a spare-time activity for which the University does not allocate time from being Director of Sommers-Bausch Observatory and Fiske Planetarium. Since I am full-time staff, it is not possible to take a month or two of time funded from the grant in which to pursue this research.

Publications using IUE observations obtained with this series of grants:

"Effective Temperatures and Gravities of S Doradus-like Stars in the Large Magellanic Cloud", B. Bohannan and J. B. Doggett 1987, *B.A.A.S.* **19**, 706.

"The Distribution of Types of Luminous Blue Variables", B. Bohannan 1989, in *IAU Colloquium 113, The Physics of Luminous Blue Variables,* ed. K. Davidson, A.F.J. Moffat, H.J.G.L.M. Lamers (Dordrecht: Kluwer), pp. 35-44.

"Of/WN Stars: More than a morphological distinction?", B. Bohannan 1990, in *Properties of Hot Luminous Stars,* Astron. Soc. of the Pacific Conference Series, Volume 7, ed. C. D. Garmany, pp. 39-43.

Publications in progress using IUE observations obtained with this series of grants:

"Fe II and [Fe II] Emission-line Stars in the Large Magellanic Cloud", B. Bohannan and J. B. Doggett.
"A Spectroscopic Analysis of the Candidate Of/WN star HD 152408", B. Bohannan and W. Schmutz.